The Earth's future climate:

1. Change in atmospheric carbon dioxide:

From the early 1700s, carbon dioxide has increased from 280 parts per million to 380 parts per million in 2005. Many scientists believe that higher concentrations of carbon dioxide in the atmosphere will enhance the greenhouse effect making the planet warmer. Scientists believe we are already experiencing global warming due to an enhancement of the greenhouse effect. Most computer climate models suggest that the globe will warm up by 1.5 - 4.5° Celsius if carbon dioxide reaches the predicted level of 600 parts per million by the year 2050 (Fig.1).

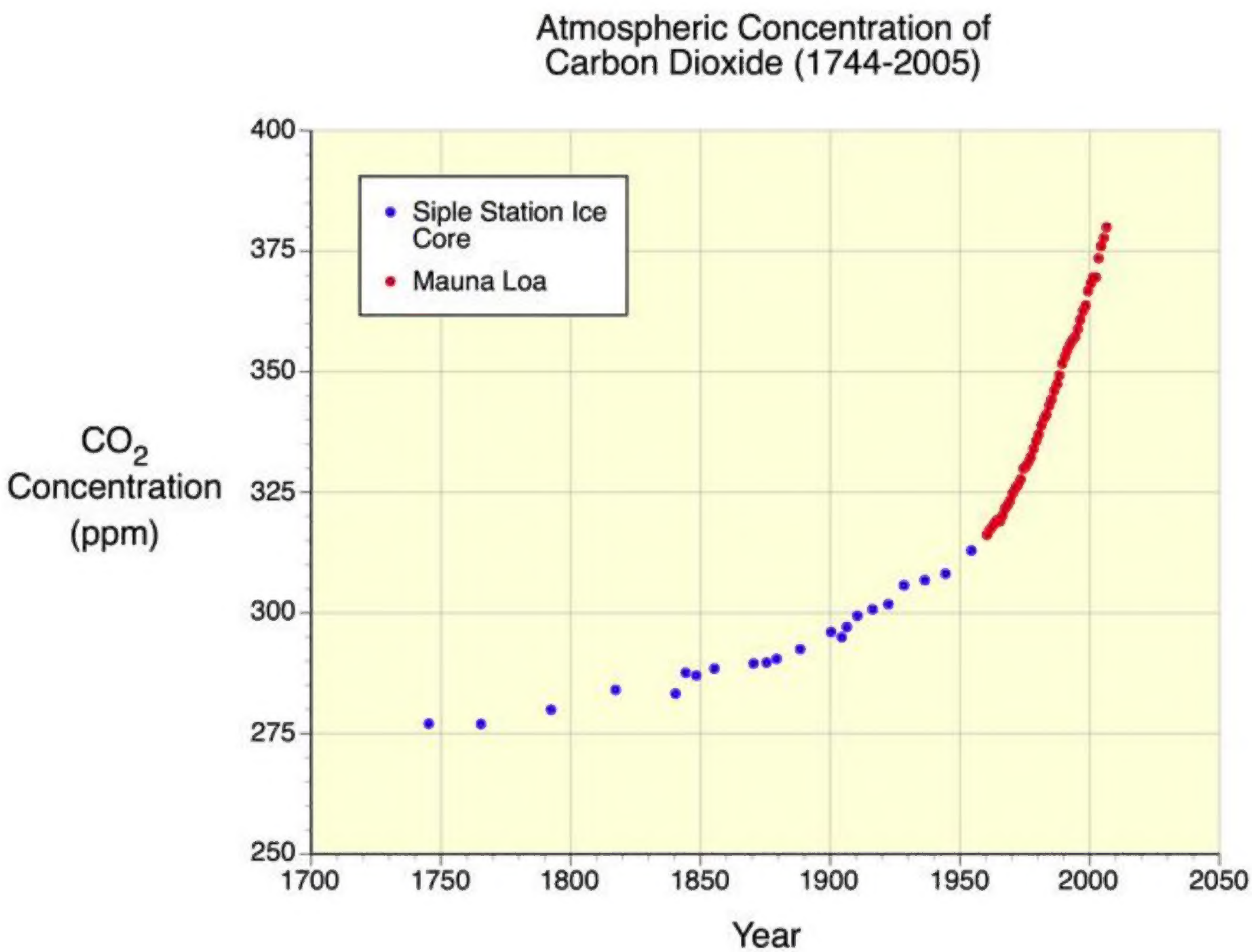

Figure 1: The graph illustrates the rise in atmospheric carbon dioxide from 1744 to 2005. Note that the increase in concentration of carbon dioxide in the atmosphere has been ***exponential***. An extrapolation into the immediate future upto 2050 would suggest continued increases.

2. Temperature:

Scientists predict that the increase of Green house gases may ***enhance*** the greenhouse effect making the planet warmer. Some experts estimate that the Earth's average global temperature has already increased by 0.3 to 0.6° Celsius, since the beginning of this century, because of this enhancement (Table 1). Predictions of future climates indicate that by the middle of the next century the Earth's global temperature may be 1 to 3° Celsius higher than today.

Table 1: Gases involved in the Greenhouse Effect: past and present concentration and sources.

Greenhouse Gas	Concentration 1750	Concentration 2003	Percent Change	Natural and Anthropogenic Sources
Carbon Dioxide	280 ppm	376 ppm	34%	Organic decay; Forest fires; Volcanoes; Burning fossil fuels; Deforestation; Land-use change
Methane	0.71 ppm	1.79 ppm	152%	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous Oxide	270 ppb	319 ppb	18%	Forests; Grasslands; Oceans; Soils; Soil cultivation; Fertilizers; Biomass burning; Burning of fossil fuels
Chlorofluorocarbons (CFCs)	0	880 ppt	Not Applicable	Refrigerators; Aerosol spray propellants; Cleaning solvents
Ozone	Unknown	Varies with latitude and altitude in the atmosphere	Global levels have generally decreased in the stratosphere and increased near the Earth's surface	Created naturally by the action of sunlight on molecular oxygen and artificially through photochemical smog production

The oceans are warming. Over the period 1961 to 2003, global ocean temperature has risen by 0.10°C from the surface to a depth of 700 m. The average rate of sea level rise from 1961 to 2003 was 1.8 ± 0.5 mm yr^{-1}. During1993 to 2003, the rate of sea level rise is estimated from observations with satellite altimetry as 3.1 ± 0.7 mm yr^{-1}. For the period 1961 to 2003, the average contribution of thermal expansion to sea level rise was 0.4 ± 0.1 mm yr^{-1}.

Due to warming of water, in low latitudes water expands & at poles ice melts and so sea level rose by about 6" in the 20^{th} century. If this trend continues sea level is predicted to rise as much as a meter by 2100. This 1 meter rise of sea level will inundate 15% of Bangladesh displacing 13 million people. Intruding water will damage the Sundarbans also.

Predicted decrease of ice cover in Arctic during the 21st Century

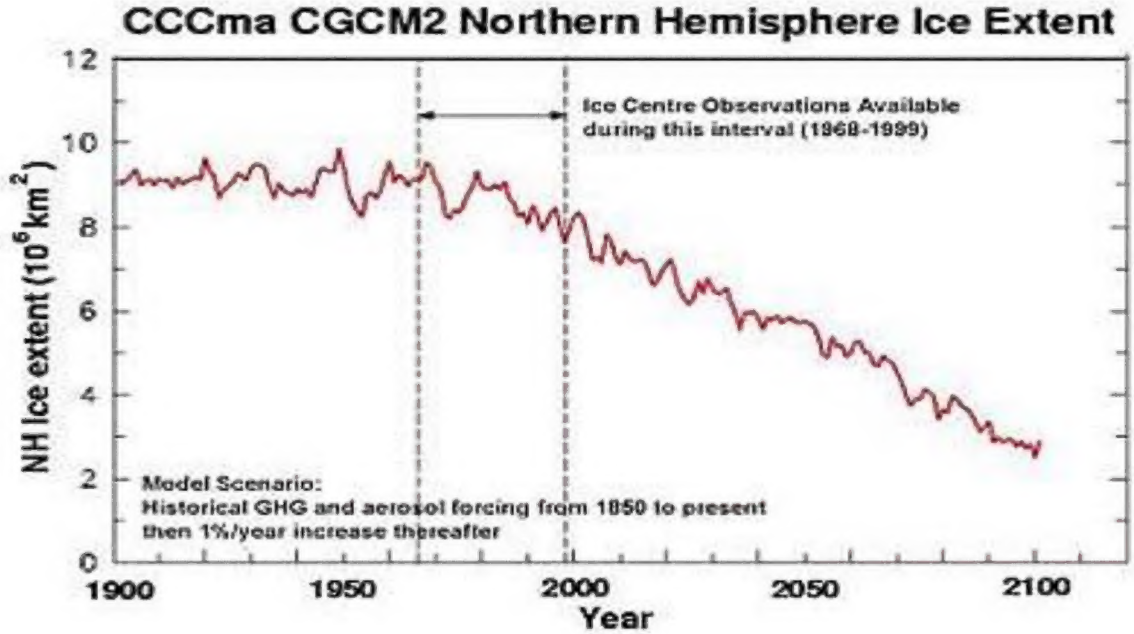

Fig.2

Emissions scenarios:

Although we have a reasonably accurate idea of the factors that control green house gas emissions, making accurate predictions of these factors is difficult. For example, predicting future population trends requires predictions of factors such as the rate of poverty, evolution of religious and social views on birth control, the rate of education of women in high-fertility regions, available healthcare in these regions, and so on.

Because it is so difficult to make a single accurate prediction of the factors that control emissions, the community of experts has avoided making a single prediction for the 21st century. Rather, a set of alternative but equally plausible *emissions scenarios* has been created. Each emissions scenario is an internally consistent vision of one way the world might evolve in the future, and the full set of emissions scenarios is designed to span a range of alternative future evolutions of the world. To drive home this point, the scenarios are not referred to as predictions but are instead described as projections. Although this may seem to be an insignificant word change, it is extremely important to keep this distinction in mind when a person thinks about the emissions scenarios.

The most well-known set of scenarios comes from the IPCC. As part of its assessment process in the late 1990s, the IPCC constructed four main emissions scenarios, each based on a different storyline of how the world might evolve over the 21st century. These four families have the extremely unimaginative names A1, A2, B1, and B2 as shown in Fig.3.

To summarize, the "A" storylines (A1, A2) describe worlds with high rates of economic growth. The "B" storylines (B1, B2) describe worlds where economic growth is slower but the Earth's resources are managed in a more sustainable way. The suffix "1" storylines (A1, B1) are worlds in which poverty is reduced and there is an overall convergence between the rich and poor, whereas the suffix "2" storylines (A2, B2) are worlds in which the current split between rich and poor remains.

A key aspect of these storylines is that they are internally consistent, so that the assumptions for population, affluence, and technology all fit together. For example, because people have fewer children as they get richer, the scenarios in which the world's poor become richer (A1, B1) feature slower population growth than the scenarios in which poverty is rampant (A2, B2). Another example is that the development and adoption of new technology requires high economic growth to support it – so the higher the economic growth scenarios (A1, B1) have more rapid adoption of new and cleaner technologies. It should also be noted that the emissions scenarios described by the IPCC all assume that the world makes no explicit effort to address climate change by reducing emissions.

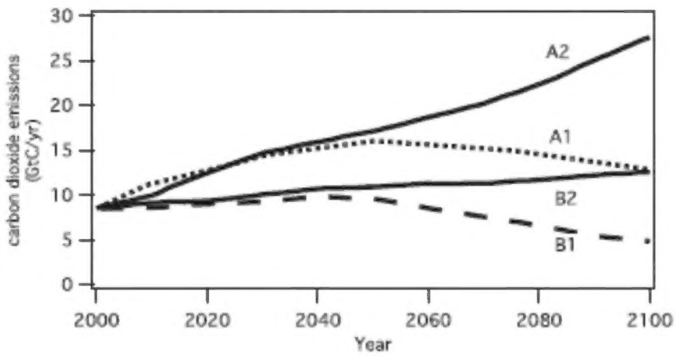

Fig.3. Emission of carbon dioxide for the four emission families. The emissions are in Gtc per year.

Figure 3.shows the rate of emissions of carbon dioxide during the 21st century, in units of GtC/yr. The B1 scenario has the lowest emissions because there is moderate population growth and strong technological development directed toward development and deployment of alternative energy sources that emit little or no carbon dioxide. This scenario predicts that emissions peak in the middle of the 21st century and decline thereafter, reaching 5 GtC/yr or so in 2100, which is approximately half of what humans are now emitting. On the other end of the spectrum is the A2 scenario. That scenario's high population growth, high economic growth directed primarily toward the rich, and slower technological development produces high emissions throughout the century. By the year 2100, emissions for the A2 scenario reach 30 GtC/yr, which is roughly three times what humans are emitting today.

Predictions of future atmospheric composition:

The next step is to take these emissions scenarios and convert them into atmospheric concentrations of greenhouse gases. This is done by feeding the emissions scenarios into a carbon-cycle model. The carbon cycle model calculates how much of the carbon dioxide emitted to the atmosphere is absorbed by the ocean and land reservoirs. The remainder stays in the atmosphere and increases atmospheric carbon dioxide.

Figure 4 shows the atmospheric carbon dioxide amounts predicted for each scenario. From an abundance of carbon dioxide of 390 ppm in 2010, the IPCC's scenarios project that atmospheric carbon dioxide abundances will be between 550 and 900 ppm in 2100. The lower limit, 550 ppm, from the B1 scenario, represents roughly twice the pre-industrial atmospheric abundance of carbon dioxide. The upper limit, 900 ppm, from the A2 scenario, represents more than a tripling of pre-industrial carbon dioxide abundances.

Of course, carbon dioxide is just one of the things that are changing our climate. There are other greenhouse gases (e.g., methane) and non-greenhouse gases (e.g., aerosols, land-use changes) that are also forcing the climate.

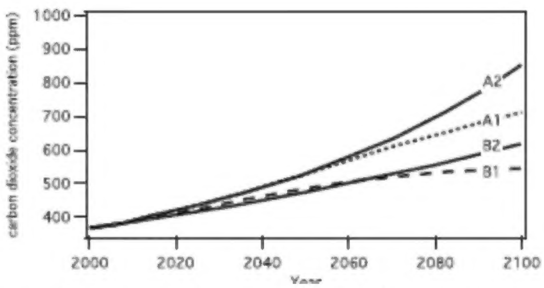

Fig. 4. Atmospheric abundances of carbon dioxide (in ppm) for the four emission families.

The same methods used to develop carbon dioxide scenarios are used to develop scenarios for all of these other things that can alter our climate.

With these estimates in the future, we can calculate the radiative forcing from each and then combine them to come up with a total projected radiative forcing. These calculations suggest that, by the end of the 21st century, total radiative forcing would be 4–8 W/m^2 above pre-industrial levels. This is a huge amount of radiative forcing – comparable to the largest variations over the past 500 million years. Such radiative forcings have changed the Earth from an ice-age planet into one that is completely ice free. And carbon dioxide is responsible for 80% of the radiative forcing that is why it is considered as the single most important factor in future climate change.

8.6 Predictions of future climate:

The estimates of atmospheric carbon dioxide abundances shown in Figure 4 are then input to climate models, which calculate a future climate for each scenario. Estimates of climates for the B1, A1B, and A2 scenarios, representing low, medium, and high rates of greenhouse-gas emissions, respectively, are shown in Figure 5. These model simulations suggest that by the end of the 21st century, the Earth will be 1.8–3.6^{0}C warmer than the late 20th century.

Also as shown in Figure 5 is Line C, which shows the predicted surface temperature if the atmospheric abundance of greenhouse gases and aerosols were stabilized at Year 2000 values. It shows that temperatures will continue to increase by 0.4^{0}C over the next several decades. This is a significant amount, comparable to the warming of the planet over the past few decades and approximately half the warming over the 20th century. Because of the enormous heat capacity of water, the Earth is not presently in thermal equilibrium and must continue to warm to reestablish energy balance. This warming is essentially unavoidable, that is why it is often referred to as “committed warming” (that is why the line is marked with the letter *C*). And because it cannot be avoided, we must adapt to it. That does not mean that all climate change is unavoidable – much of the warming over the 21st century could still be avoided if we take prompt action.

The right-hand panel in Figure 5 shows the likely range of temperatures in 2100 predicted for each scenario, as well as the A1T and A1FI scenarios. This range is generated by taking the same emissions scenarios and running them through a large number of different climate models. Because each model handles the details of the physics of the atmosphere differently, it produces slightly different results.

This allows us to separately estimate the uncertainty in predicted temperature in Year 2100 as a result of uncertainties in emissions scenarios and uncertainty in the physics of the climate models. Figure 8.5 shows that the difference in projected temperature in 2100 between the low-end (B1) and high-end (A2) scenarios is approximately a factor of 2. Figure 5 also shows that, for a single emissions scenario, there is a similar factor of 2 differences between the highest temperature predicted by the group of models and the lowest temperature. Thus, the

uncertainty in predicted temperature in 2100 is approximately evenly split between uncertainty in emissions and uncertainty in the physics of climate.

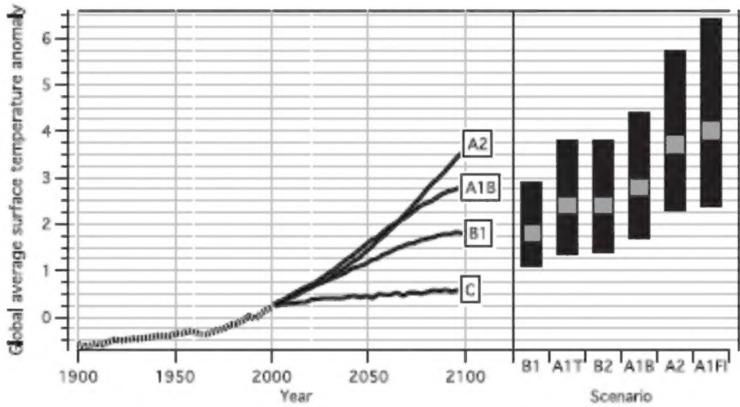

Fig.5. Model estimates of global annual average surface temperature for the B1, A1B, and A2 scenarios (relative to the 1980–1999 average), along with the predicted surface temperature (C) if the atmospheric abundance of greenhouse gases and aerosols were stabilized at Year 2000 values. The bars at right are the likely range of temperatures for each scenario, where the lighter portions are the most likely temperatures. The range of temperatures is derived by using a set of climate models.

8.6.2 Climate change beyond 2100:

Even though the emissions (as shown in Figures 3 through 5) stop in the Year 2100, the associated climate change is not going to stop in 2100. In fact, many scenarios have significant emissions and warming that extend into the 22nd century and well beyond.

Though exactly how long these emissions can continue is not known, everyone agrees that fossil fuels will eventually run out, and emissions from their combustion will therefore cease. Although many experts think that this will happen in the next century or two, the exact timing and estimates of how much carbon will be emitted to the atmosphere is not known. The range of total emissions extends from about1,500 GtC to more than 5,000 GtC. These estimates are all well above the 300 GtC or so that humans have already emitted into the atmosphere over the past few centuries. And it should be remembered that lags in the climate system, as well as slow feedbacks, have the capacity to continue the warming long past the cessation of emissions.

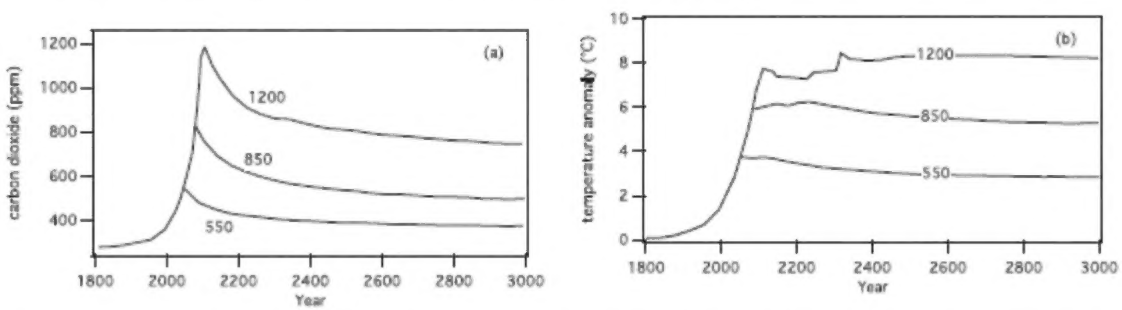

Fig.6. (a) Amount of carbon dioxide in the atmosphere as a function of time, for the next 1,000 years. Carbon dioxide emissions rise at 2% per year until it hits a peak abundance (550, 850, and 1,200 ppm); then emissions are decreased instantly to zero. (b) The temperature time series corresponding to each carbon dioxide time series

This long residence time of carbon dioxide in our atmosphere is shown in Figure 6a, which shows atmospheric carbon dioxide over the next 1,000 years for emissions scenarios where atmospheric carbon dioxide increases until it reaches 550, 850, and 1,200 ppm, at which point emissions from human activity decline instantly to zero. Even by Year 3000, eight to nine centuries after carbon dioxide emissions ceased, atmospheric carbon dioxide in all scenarios

remains well above pre-industrial values (280 ppm). This is simply a reflection of how long it takes for an addition to atmospheric carbon dioxide to be removed from the atmosphere.

The temperatures associated with each carbon dioxide time series are shown in Figure 6b. Even after emissions cease, the temperatures do not decline significantly over the next 1,000 years. This is a consequence of three factors. First, carbon dioxide remains elevated throughout the millennium, so it continues to heat the planet even after emissions stop. Second, the ocean's large heat capacity means that the planet cools off very slowly. This is the flip side of the situation in which the warming lags the carbon dioxide – the cooling will lag any decrease in atmospheric carbon dioxide abundance. Third, the slow feedbacks, such as the loss of the big ice sheets, will act to oppose any cooling.

Uncertainty:

There is considerable uncertainty as how the cryosphere will respond to global warming. Will the Arctic pack ice continue to retreat, offering the possibility of new trans-Arctic shipping routes? Will Greenland become ice free, as it apparently was at the time of the last interglacial period? Will the melting of the ice sheets be sufficiently rapid to accelerate the rate of sea level rise? How serious is the risk of a "climate change" — for example, a sudden disintegration of a major part of one of the ice sheets or a reorganization of the atmospheric and ocean general circulation analogous to those that caused the abrupt discontinuities in ice core records? Such complex workings of the Earth system are beyond the capability of the present generation of coupled models to simulate.